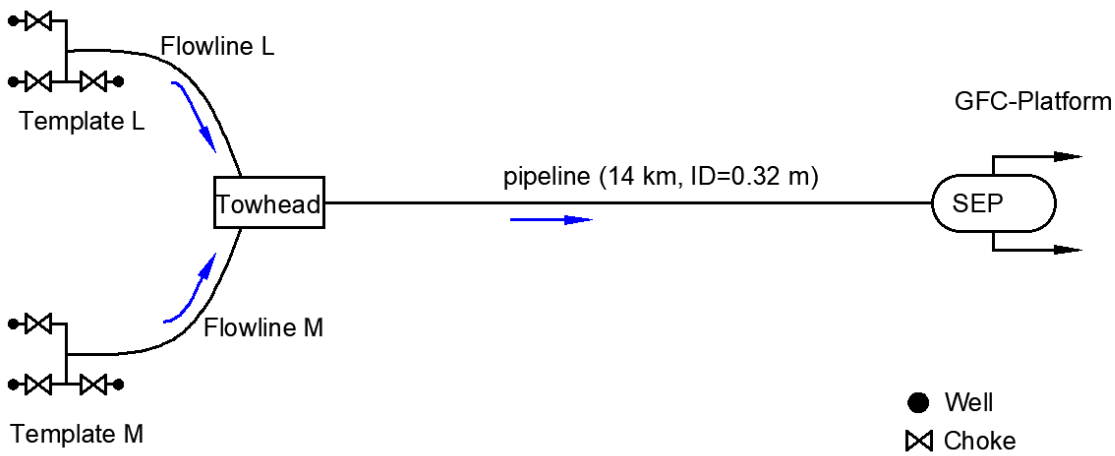
PROBLEM (60 POINTS)

A reservoir unit in Gullfaks South field (Block 13) is planned to produce gas condensate (with a condensate-gas ratio of 3E-4 Sm^3/Sm^3) by two subsea templates (Template L and M) with a total of 6 wells (3 in each template). The production is commingled in a manifold (called "Towhead") and is transported further using a production pipeline to the Gullfaks C platform.



Initial reservoir pressure is 240 bara and initial gas in place, G, is 72 E9 Sm^3. The reservoir will be produced is produced in plateau mode with a total rate of 10 E6 Sm^3/d. The production is controlled with the wellhead chokes. After the field enters in decline, it will be produced until the economic rate of 6E06 is reached. At this time, the field will be abandoned.

Task 1. Compute the production profile of the field starting at end of year zero and until abandonment. Keep in mind that in the decline phase the choke pressure drop should be zero and the field rate below the plateau rate. Explain how you performed your calculations.

Task 2. The operator is evaluating to install a subsea wet gas compressor at the towhead to extend the plateau period and improve the recovery factor of the field. However, such a compressor could cost in the range of 0.5 to 1 1E09 USD, and the company would like you to estimate if it will be worthwhile to install it. **The compressor station can provide a maximum of 35 bara pressure boost and has a total maximum power of 10 MW.**

To provide management with a recommendation, do the following:

- **a)** Re-compute the production profile assuming that, once the field reaches the end of plateau, the compressor will enter in operation. The goal of installing the compressor is to maintain plateau rate, but keep in mind that, at some point in time you might need to adjust the field rate to meet the maximum pressure boost and maximum power constraints of the compressor.
- **b)** With the production profile compute the net present value considering revenue only.
- **c)** With the results of task 1, compute the net present value considering revenue only.
- **d)** Compare the difference between the numbers obtained in b) and c) to determine if it is worthwhile to install the compressor.

Explain how you performed your calculations.

Suggestions:
Being a preliminary study, considerable simplifications and assumptions will be used:

- Depletion and recovery characteristics can be modeled with a dry gas reservoir tank model.
- The flow in the wells, flowlines and the pipeline can be represented by isothermal flow equations for dry gas (the presence of condensate is ignored).
- Consider that all wells **are identical** (i.e. produce the same, so it is necessary to model only one well).
- Wells are equipped with wellhead chokes to control the rate when required.
- Perform your calculations on a yearly basis.
- Use the following equations (available in VBA):

Material balance: $$p_R = p_{Ri} \cdot \left(1 - \frac{G_p}{G}\right)$$
Inflow equation: $$q_g = C_R \cdot \left(p_R^2 - p_{wf}^2\right)^n$$ C_R= 1000 $Sm^3/d/bar^{2n}$ n= 0.8
Tubing equation: $$q_{gsc} = C_T \cdot \left(\frac{p_{wf}^2}{e^S} - p_{wh}^2\right)^{0.5}$$ C_T = 3.8 E4 $Sm^3/d/bar$ S = 0.43
Flowlines Template-Towhead: **Neglect the pressure drop in the flowlines from templates to towhead** **Therefore, when the wellhead choke is fully open:** $$p_{wh} = p_{TH}$$ **When wellhead chokes are partially closed:** $$p_{wh} - p_{TH} = \Delta p_{choke}$$ **When there is a compressor at the towhead:** $$p_{TH} - p_{wh} = \Delta p_{compressor}$$
Pipeline equation Towhead-separator: $$q_{gsc} = C_{PL} \cdot \left(p_{TH}^2 - p_{sep}^2\right)^{0.5}$$ C_{FL} = 1.4 E5 $Sm^3/d/bar$ p_{sep} = 60 bara

- It is recommended to solve the problem using the Excel sheet provided with the pre-programmed VBA functions. Use the Excel Solver or GoalSeek when needed.
- Use the rectangle integration rule to estimate cumulative gas production during the year. For example, to calculate the cumulative production of year 1, assume the rate at end of year zero is kept constant through year 1.
- Compression power (available as a VBA function, Power_c):

$$Power = \left(\left(\frac{p_{dis}}{p_{suc}}\right)^{\frac{n-1}{n}} - 1\right) \cdot T_{suc} \cdot Z_{av} \cdot R \cdot \frac{k}{k-1} \cdot \frac{\dot{m}}{\eta_m}$$

with

p_{dis}	Discharge compressor pressure [bara]
p_{suc}	Suction compressor pressure [bara]
n	Polytropic exponent. Assume equal to 1.45
T_{suc}	suction compressor temperature [K]. Assume equal to 300 K
Z_{av}	Average gas deviation factor between compressor discharge and suction. Assume equal to 1.
R	Specific gas constant [J/kg K], universal gas constant (8314.462 J/kmol K) divided by molecular weight of gas (16).
$\dot{m}$	Mass flow [kg/s]. Assume equal to field gas rate multiplied by density of gas at standard conditions (0.67 kg/m3)
η_m	Mechanical efficiency (assume equal to 0.98)
k	Heat capacity ratio, assume equal to 1.37

For estimating the NPV of the revenue use the following equation, that considers sales of condensate and gas:

$$NPV_{rev} = \sum_{j=1}^{N} \frac{\Delta G_{p,j}}{(1+i)^j} \cdot \left(C_{gr} \cdot P_o + P_g\right)$$

i	Discount rate (use 0.08 1/year)
j	Counter for the number of years
N	Total number of years until abandonment
$\Delta G_{p,j}$	Field gas production of year "j"
P_o	price per Sm^3 of oil, [300 USD/Sm^3]
P_g	price per Sm^3 of gas, [0.15 USD/Sm^3]
C_{gr}	Condensate-gas ratio, 3 E-4 Sm3/Sm3